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THE DISTRIBUTION OF COSMIC RAYS IN THE GALAXY  
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 $\gamma$ -RAY OBSERVATIONS

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# ABSTRACT

Recent data from SAS-2 on the galactic  $\gamma$ -ray line flux as a function of longitude reveal a broad maximum in the  $\gamma$ -ray intensity in the region  $|\ell| \lesssim 30^\circ$ . These data, when unfolded, imply that the low-energy (1-10 GeV) galactic cosmic-ray flux varies with galactocentric distance and is about an order of magnitude higher than the local value in a toroidal region between 4 and 5 kpc from the galactic center. We further show that this enhancement can be plausibly accounted for by first-order Fermi acceleration, compression and trapping of cosmic-rays consistent with present ideas of galactic dynamics and galactic structure theory. Our calculations indicate that cosmic-rays in the 4 to 5 kpc region are trapped and accelerated over a mean time of the order of a few million years or about 2 to 4 times the assumed trapping time in the solar region of the galaxy. Cosmic-ray nucleons, cosmic-ray electrons and ionized hydrogen gas are found to have a strikingly similar distribution in the galaxy according to both the observational data and the theoretical model discussed here.

## INTRODUCTION:

Recent observations of galactic  $\gamma$ -radiation above 30 MeV obtained from the second Small Astronomy Satellite (SAS-2) as reported by Kniffen, et al. (1973) have confirmed the earlier results of Kraushaar, et al. (1972) indicating a large increase of  $\gamma$ -ray flux in the direction of the galactic center. The data obtained from SAS-2 with somewhat better angular resolution than that obtained by the OSO-3 detector, revealed a broad, fairly flat maximum in the intensity distribution of the radiation from the galactic plane extending over a  $60^\circ$  longitude interval centered on the galactic center (i.e.,  $|\ell| \lesssim 30^\circ$ )<sup>1</sup>. It has been shown previously that the flux of radiation from the galactic plane in the disk region away from the galactic center ( $|\ell| \gtrsim 60^\circ$ ) can be accounted for as arising from the interactions of cosmic rays having the intensity observed in the solar region of the galaxy with interstellar gas having the column density of neutral hydrogen observed in the galactic plane (Kraushaar, et al. 1972, Stecker 1973 (and references therein), Kniffen, et al. 1973). In our previous letter (Stecker, et al. 1974), we showed that the  $\gamma$ -ray spectrum in the inner galaxy as reported by Kniffen, et al. (1973) could be described as

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<sup>1</sup>We will adopt here negative longitude designations such as  $-30^\circ$  instead of the more conventional  $330^\circ$  because such designations lend themselves more naturally to a mathematical discussion of the flux distribution owing to a large amount of symmetry around the galactic center.

consisting of 70 per cent  $\pi^0$ -decay radiation produced from the same type of interaction process which could account for the general disk radiation with an additional 30 per cent contribution that can be accounted for as arising from Compton interactions of cosmic-ray electrons with the larger radiation fields existing in the inner galaxy. In that letter, an explanation was proposed for the enhanced  $\gamma$ -ray flux from the inner galaxy as primarily due to an enhancement in the cosmic-ray intensity in the inner galaxy caused by the large-scale acceleration and compression of cosmic-rays. We will undertake here a more detailed examination of that picture based on an actual unfolding of the SAS-2 longitude distribution data.

## II. UNFOLDING OF THE LONGITUDE DISTRIBUTION OF THE GALACTIC RADIATION AND THE IMPLIED COSMIC-RAY DISTRIBUTION.

If we assume that the  $\gamma$ -ray production rate in the galactic plane  $Q$  is only a function of galactocentric distance  $\varpi$ , we have basically a two-dimensional problem in cylindrical coordinates with no azimuthal dependence and symmetry in the longitude distribution about  $0^\circ$  longitude. The SAS-2 data are suggestive of some asymmetry (Kniffen, et al. 1973, Stecker, et al. 1974) but such asymmetry does not appear to be pronounced. With the assumption  $Q = Q(\varpi)$ , the  $\gamma$ -ray line intensity in photons per  $\text{cm}^2 \cdot \text{s} \cdot \text{rad}$  as a

function of galactic longitude  $I_Y(\ell)$  can be expressed in the form

$$I_Y(\ell) = \frac{R_\odot}{2\pi} \int_0^{b_M} db \int_0^{(h/R_\odot) \cot b} d\rho Q(\tilde{\omega}) \quad (1)$$

where  $R_\odot$  is the galactocentric distance of the sun (10 kpc) and  $h$  is the half-width of the gas disk of the galaxy. The quantities  $\tilde{\omega}$  (galactocentric distance) and  $\rho$  (heliocentric distance) will be given in natural galactic units (1 galactic unit = 10 kpc) so that  $\rho = \cos \ell \pm (\tilde{\omega}^2 - \sin^2 \ell)^{1/2}$ . The galactic latitude is denoted by  $b$  and we assume that the observations are made with a detector which integrates the flux over all contributing latitudes up to  $b_M$ .

For the purposes of analysis, we will assume that the production rate  $Q$  in the outer part of the galaxy is roughly constant and equal to  $Q_o$  for  $0.8 < \tilde{\omega} < 1.5$ , neglecting some possible effects from the outer arms, and is equal to 0 outside of this toroidal region. In the inner galactic region, we will take  $Q$  to be equal to some function  $Q_i$  to be determined for  $\tilde{\omega} < \tilde{\omega}_M = 0.8$  and  $Q_i = 0$  for  $\tilde{\omega} > \tilde{\omega}_M$ . The observed flux,  $I_Y(\ell)$  can then be written as the sum of an inner-galactic component  $I_i$  and an outer-galactic component  $I_o$  where

$$I_Y = I_i + I_o$$

$$I_o(\ell) = R_\odot/2\pi \int_0^{b_M} db \int_0^{(h/R_\odot) \cot b} d\rho Q_o(\tilde{\omega}) \quad (2)$$

and  $I_i$  may be expressed in the form

$$I_i(\ell) = \frac{h \cos \ell}{2\pi} \int_{\sin^2 \ell}^{\tilde{\omega}_M^2} d\tilde{\omega}^2 \frac{Q_i(\tilde{\omega})}{(1-\tilde{\omega}^2)(\tilde{\omega}^2 - \sin^2 \ell)^{1/2}} \quad (3)$$

By expressing the observed flux in the form given by equations (2) and (3), one can obtain a unique solution for the production rate in the inner galaxy,  $Q_i(\tilde{\omega})$  which can be found by inverting the convolution integral in equation (3). Equation (3) is a type of Abel equation which may be solved by the method of Laplace transforms. We then obtain the result

$$Q_i(\tilde{\omega}) = \frac{2(1-\tilde{\omega}^2)}{h} \int_{\tilde{\omega}^2}^{\tilde{\omega}_M^2} d\eta (\eta - \tilde{\omega}^2)^{-1/2} \left[ \frac{d}{d\eta} \left( -\frac{I_i}{\cos \ell} \right) \right] \quad (4)$$

where  $\eta \equiv \sin^2 \ell$ .

In order to determine  $Q_i$ ,  $Q_o$  is first chosen to fit the data obtained by Kniffen, et al. near the anticenter direction. Then using the interpolation of the SAS-2 data shown in Figure 1,  $I_i$  is obtained from equation (2). The production rate in the inner galaxy  $Q_i(\tilde{\omega})$  is then calculated from equation (4) using average values for the quantity  $[d/d\eta (-I_i/\cos \ell)]$  averaged over  $10^\circ$  longitude intervals consistent with the form of the SAS-2 results.  $I_i$  and the average value of

$dI_i/d\ell$  are shown in Figure 2 and the results obtained for  $hQ(\tilde{\omega})$  are shown in Figure 3. We then define the quantity  $q_\odot$  taken to be equal to the  $\gamma$ -ray production rate per HI atom per second from cosmic-ray-gas interactions in the solar galactic region. This quantity,  $q_\odot$  is found to be equal to  $(1.3 \pm 0.2) \times 10^{-25} \text{ s}^{-1}$  from an analysis of recent accelerator data (Stecker 1973). The cosmic-ray enhancement factor in the galaxy  $I_{\text{cr}}/I_\odot$  (taken relative to the value in the solar vicinity) is then given by

$$I_{\text{cr}}/I_\odot = \frac{(hQ)}{q_\odot n_{\text{HI}}(h\xi)} \quad (5)$$

where  $n_{\text{HI}}$  is the density of atomic hydrogen seen in 21 cm radio emission and  $\xi$  is a factor representing the amount of cool atomic hydrogen and molecular hydrogen not seen in the 21 cm radio surveys. For further analysis, we will assume that the value of  $(h\xi)$  is independent of galactocentric distance  $\tilde{\omega}$ . The distribution  $n_{\text{HI}}(\tilde{\omega})$  has been discussed by various authors (Kerr (1969), Westerhout (1970), Shane (1972), Sanders and Wrixon (1973). These data are summarized in Figure 4. Using the data given in Figures 3 and 4, we have used equation (5) to obtain the cosmic-ray enhancement factor  $(I_{\text{cr}}/I_\odot)$  as a function of galactocentric distance as shown in Figure 5. The normalization  $I_{\text{cr}}/I_\odot(\tilde{\omega}=1)=1$  gives a value for  $h\xi$  of  $\sim 140 \text{ pc}$  for the intensity of  $\gamma$ -rays observed by SAS-2. This is a reasonable value for the galaxy as



previously discussed by Stecher and Stecker (1970).

The values for  $hQ$  given in Figure 3 are evaluated from equation (4) by integrating inward toward the galactic center. For this reason, the relative uncertainty in the value of  $hQ$  increases near the galactic center as shown in Figure 3. Keeping this in mind, we can draw the following conclusions:

1. The production rate of galactic  $\gamma$ -radiation has a strong variation with galactocentric distance. Since the spectrum of this radiation indicates a cosmic-ray production origin, this implies that the cosmic-ray intensity is not uniform in the galaxy.

2. The 1-10 GeV cosmic-ray intensity in the toroidal region defined by  $0.4 < \varpi < 0.5$  exhibits a strong maximum as shown in Figure 5, indicating the cosmic-ray intensity in this region is roughly an order of magnitude higher than in the galactic region in the solar vicinity.

### III. COMPARISON OF THE COSMIC-RAY AND $\gamma$ -RAY DATA WITH OTHER LARGE-SCALE FEATURES IN THE GALAXY.

The radial distribution of  $\gamma$ -radiation (Figure 3) and implied distribution of cosmic-ray nuclei (Figure 5) bear a striking resemblance to the distribution of another galactic parameter which is of importance to galactic structure studies, viz., the ratio of ionized to neutral hydrogen in

the galaxy  $n_{\text{HII}}/n_{\text{HI}}$ . As we pointed out in our previous letter (Stecker, et al. 1974), the overall fraction of hydrogen gas ionized in the galaxy in the so-called "giant HII regions" has a similar radial distribution (Reifenstein et al. 1969, Mezger 1970) which has been related to the formation of young hot stars in spiral arms triggered by density waves in the density wave theory of spiral structure (see e.g. Oort 1973, Shu 1973). However, an increase in the low-energy sub-relativistic cosmic-ray intensity related to the increase in the 1-10 GeV cosmic-ray intensity deduced here may also play a significant role in accounting for the HII/HI distribution as suggested to us by G. Field (private communication). The correlation between  $I_{\text{cr}}/I_{\odot}$  and HII/HI is quite dramatic as shown in Figure 6. The dashed line in Figure 6 also shows a function given by Shu (1973) to correlate HII/HI with a compression factor given by the density wave model. The asymptotic dashed line between 3 and 4 kpc corresponds to the inner Lindblad resonance in this model. We have previously suggested that compression and acceleration can account for the enhancement of cosmic-rays implied for the 4 to 5 kpc region (Stecker, et al. 1974) as related to the "expanding arm" model (Oort 1970, Van der Kruit 1971) and will further elaborate on that hypothesis here, but we note that whatever the actual cause, be it expanding arm or density wave (Roberts 1970, 1973) it is the compression it-

self which can account for the increase in  $I_{\text{cr}}/I_{\odot}$ .

There is a similar increase in observed non-thermal radio emission from high energy electrons toward the galactic center, but the situation with the non-thermal emission is more complex. Here also compression and acceleration effects acting on the cosmic-ray electrons together with an enhanced magnetic field strength are expected for the compressed region between 4 and 5 kpc and can be invoked to explain the data on non-thermal radio emission.

In a recent review, Price (1973) has discussed the longitude distribution of the non-thermal radio background at 150 MHz. This distribution, as given by Price, is shown in Figure 7 along with the SAS-2  $\gamma$ -ray data and a model constructed by Price to account for the distribution of the radio data. One can see from Figure 7 that there is a general correlation between the  $\gamma$ -ray and radio distributions for  $|\ell| \geq 30^\circ$  which is not surprising if the cosmic-ray electron and proton components are roughly proportional and the square of the magnetic field strength  $B^2 \sim n_H$ . The correlation can be extended to the entire longitude range, if it is assumed that the peak in the radio intensity at  $\ell=0^\circ$  can be attributed to a purely non-thermal radio emission region at the galactic center (Price 1973). The rest of the emission has been accounted for by Price's model shown in

Figure 7 which supposes a general  $e^{-\varpi/\varpi_0}$  flux distribution (similar to that we proposed for the  $\gamma$ -radiation (Stecker et al. 1974)) with superimposed, relatively small variations due to smaller enhancements in the spiral arms. The maxima at  $20^\circ < |\ell| < 30^\circ$  evident in the  $\gamma$ -ray data are not obvious in the radio data. One reason for this may be the relative thickness of the radio disk of the galaxy as compared with the gas disk.

#### THE ACCELERATION MODEL:

An enhancement of cosmic-rays in a localized region of the galaxy can be due to three factors (1) an increase in the density of cosmic-ray sources (or alternatively the production rate) in the region (2) an increase in the trapping time (escape time) of cosmic-rays in the region, and (3) acceleration and compression of cosmic-rays in the region. We may write this as follows:

$$\ln(I_{\text{cr}}/I_\odot) = \ln(Q_{\text{cr}}/Q_\odot) + \ln(T_{\text{cr}}/T_\odot) + \delta \quad (6)$$

where the first term on the right hand side of equation (6) represents the enhancement in the production rate, the second term represents the trapping factor and the third time  $\delta$  represents the effect of acceleration and compression. The first term can only be guessed at, given our present

lack of knowledge of the ultimate origin of cosmic rays. However, as an indication of the possible effect of source density, one can note the distribution of supernova remnants in the galaxy which may be proportional to the density of cosmic-ray sources if we assume that cosmic-rays are produced by supernova explosions (Ginzburg and Syrovatsky 1964) or in remnant pulsars (Gunn and Ostriker 1969). According to Ilovaisky and Lequeux (1972) the density of supernova remnants increases roughly by a factor of 2 over the local galactic value for  $\tilde{\omega} < 0.8$  and drops sharply for  $\tilde{\omega} > 1.2$ . A more recent study by Clark, et al. (1973) is probably less susceptible to selection effects because their survey included remnants down to lower luminosity levels. The results obtained by Clark, et al. confirm the earlier results of Ilovaisky and Lequeux regarding the general distribution of supernova remnants in the galaxy. We will therefore estimate here that  $Q_{cr}/Q_{\odot} \approx 2$  for the enhanced region  $0.4 < \tilde{\omega} < 0.6$ . This factor, by itself, cannot account for the order-of-magnitude enhancement deduced for  $I_{cr}/I_{\odot}$ .

The second factor,  $T_{cr}/T_{\odot}$  is so difficult to estimate that we will treat it as a free parameter  $>1$  to be solved for. It is not unreasonable to expect more effective trapping in the inner galaxy (i.e.  $T_{cr}/T > 1$ ) due to compression and a resultant stronger magnetic field strength.

The factor  $\delta$  can be broken up into two parts, an acceleration factor  $\delta_{\text{ACC}}$  which accounts for acceleration of the more numerous lower energy cosmic-rays (given an assumed power-law differential energy spectrum of the form  $\propto E_{\text{cr}}^{-\Gamma}$ ) to an energy above the threshold for  $\pi^0$  production, and a simple density enhancement ( $\delta_D$  due to the lower volume of the compressed region in which the trapped particles find themselves. If we designate the specific volume compression rate by

$$\alpha = -(1/V) (dV/dt) \quad (7)$$

then obviously

$$\delta_D = \alpha T_{\text{cr}} \quad (8)$$

The acceleration factor can be estimated thermodynamically. Regardless of the exact details of this process, which may be a coherent, first order Fermi acceleration which can transfer the momentum of moving "clouds" with trapped magnetic irregularities to cosmic-rays trapped in the compressed region (Fermi 1954, Stecker et al. 1974), the increase in the energy of the individual cosmic-rays can be treated as an adiabatic compression heating of a "cosmic-ray gas molecule". The energy-volume relation then gives the energy enhancement factor as

$$\ln(E/E_0) = (\gamma-1)\alpha T_{\text{cr}} \quad (9)$$

where  $\gamma = \frac{4}{3}$  for relativistic cosmic-rays  $\gamma = \frac{5}{3}$  for sub-relativistic cosmic-rays. For a cosmic-ray differential energy spectrum of the form  $I_{cr} \propto E^{-\Gamma}$ , we then find

$$\delta_{acc} = (\Gamma-1)(\gamma-1)\alpha T_{cr}$$

and therefore

(10)

$$\delta = [(\Gamma-1)(\gamma-1)+1]\alpha T_{cr}$$

(Stecker, et al. 1974). The value of the specific volume compression rate  $\alpha(\varpi)$  can be given in terms of the radial expansion velocity  $v_r$  of the gas deduced from the 21 cm observations of the "expanding arm" feature. Under this interpretation

$$R_{\odot}\alpha(\varpi) = \frac{dv_r}{d\varpi} - \frac{v_r}{\varpi}$$

The function of  $\alpha(\varpi)$  deduced from the observations of  $v_r(\varpi)$  (Shane 1972, Sanders and Wrixon 1972, 1973) is shown in Figure 8. It is positive and maximal in the region of observed maximum  $\gamma$ -ray emission (see Figure 3) and is negative in the inner region  $\varpi < 3$  kpc where there may be a significant drop in  $\gamma$ -ray emission, although the uncertainties in that region are very large.

Because of the large uncertainties in  $T_{cr}$  and  $T_{\odot}$  we will consider a range of values for  $T_{cr}$  and  $T_{cr}/T_{\odot}$ . We will consider  $3 \times 10^6 < T_{cr} < 3 \times 10^7$  yr where the upper limit on  $T_{cr}$  is taken to be the deduced age of the expanding feature (Oort 1970, Van der Kruit 1971). The cosmic-ray lifetime

in the local region,  $T_{\odot}$ , is given by O'Dell, et al. (1973) and Brown et al. (1973), to be  $10^6 \text{yr} < T < 10^7 \text{yr}$ . Taking  $\alpha = 2 \times 10^{-15} \text{s}^{-1}$  in the region of maximum compression (see Figure 8) and assuming  $I_{\text{cr}}/I_{\odot} \approx 15$  and  $Q_{\text{cr}}/Q_{\odot} \approx 2$ ,  $\Gamma \approx 2.5$ ,  $\delta \approx 1.75 \alpha T_{\text{cr}} = 1.5 \times 10^{-15} T_{\text{cr}}$ , the value given for the parameters  $T_{\text{cr}}/T_{\odot}$ ,  $e^{\delta}$  and  $T_{\text{cr}}$  and  $T_{\odot}$  consistent with equation (6) are given in Table 1. The factor  $e^{\delta}$  represents the enhancement effect due to acceleration and compression.

#### CONCLUSION:

Our results indicate that the galactic  $\gamma$ -ray production rate, and by implication, the cosmic-ray nucleon intensity in the galaxy rises to a sharp maximum in a toroidal region between 4 and 5 kpc from the galactic center. This distribution is strikingly similar to that observed for ionized hydrogen in the galaxy and the radio-emission model of Price (1973). However, no such correlation is observed with the neutral hydrogen distribution. The fact that the average neutral hydrogen distribution in the galaxy peaks in the outer region between 13 and 14 kpc from the galactic center and falls slowly inward toward the galactic center (see Figure 4) strengthens the argument that the cosmic-rays themselves must increase sharply in the 4 to 5 kpc region in order to explain the observed  $\gamma$ -ray longitude distribution. One should note that the strong 4 to 5 kpc maximum



appears to lie on the inside of an arm as is the case with the HII maximum.

It seems reasonable to expect relatively small perturbations superimposed on this general pattern due to some concentration of cosmic-rays in the spiral arms as in the model of Price (1973). These perturbations have been neglected here along with possible fluctuations due to dense clouds (Black and Fazio 1973) and perturbations at galactocentric distances greater than 8 kpc. Therefore, our assumptions of constant  $h\xi$  throughout and constant  $hQ$  for  $\omega > 0.8$  should not be taken too seriously but they should represent average values indicating no strong features in this range. More detailed studies of galactic  $\gamma$ -rays with better angular resolution should reveal the finer scale perturbations mentioned above.

It thus appears that, as has been hoped by many over the last decade,  $\gamma$ -ray observations have begun to reveal important information on the large-scale distribution of galactic cosmic-rays. This information would appear to support the galactic origin hypothesis for most cosmic-rays (see e.g. Ginzburg and Syrovatsky 1964).

Moreover, our calculations indicate that large-scale compression and first order Fermi acceleration may be occurring in the inner galaxy as previously suggested

(Stecker, et al. 1974). Such a model supplements our ideas on galactic structure as revealed by radio and optical data.

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Table I. Lifetime of Cosmic-Rays in the 4 to 5 kpc Region  
Calculated from the Acceleration-Compression Model

$T_{\text{cr}}/T_{\odot}$	$e^{\delta}$	$T_{\text{cr}} (10^6 \text{y})$	$T (10^6 \text{y})$
2	3.7	12.6	6.3
3	2.5	8.7	2.9
4	1.9	6.0	1.5

FIGURE CAPTIONS:

- Figure 1. Distribution in galactic longitude of the galactic  $\gamma$ -ray line flux as observed by OSO-3 (Kraushaar, et al. 1972) and SAS-2 (Kniffen, et al. 1973) normalized arbitrarily for purposes of comparison. Statistical uncertainties quoted for these results (not plotted) are significantly greater for the OSO-3 results as compared with the SAS-2 results. The interpolation of the SAS-2 data was obtained on the assumption of a smooth average variation in the  $\gamma$ -ray production rate as discussed in the text.
- Figure 2. The function  $I_1(\ell)$  as defined in the text obtained by using the SAS-2 data for  $\ell < 50^\circ$  and defining  $I_1(\ell) \equiv 0$  for  $\ell > 60^\circ$ . The values for  $dI_1/d\ell$  used for calculating the  $\gamma$ -ray production rate  $Q_1(\varpi)$  were obtained from the slopes of the jagged line shown in the figure.
- Figure 3. The value for  $hQ(\varpi)$  calculated from equations (2) and (4) as discussed in the text. A constant value for  $hQ$  is assumed for  $R_0\varpi > 8\text{kpc}$ . Uncertainties in the determination of the value of  $hQ(\varpi)$  as evaluated from the integral equation (4) grow quite large in the central region  $\varpi < 4\text{ kpc}$ .

Figure 4. The neutral hydrogen density  $n_{\text{HI}}(\tilde{\omega})$  based on the discussion of Kerr (1969), Shane (1972), and Sanders and Wrixon (1973).

Figure 5. The calculated cosmic-ray distribution relative to the flux in the solar vicinity ( $I_{\text{cr}}/I_{\odot}$ ). A mean constant value for  $R \gg 8$  kpc is assumed. For purposes of calculation, it is assumed that  $h\xi$  is a constant which is evaluated to be  $\approx 140$  pc.

Figure 6. The correlation between  $I_{\text{cr}}(\tilde{\omega})$  and  $\text{HII/HI}(\tilde{\omega})$  is shown here. Also shown is a theoretical function used by Shu (1973) in discussing the observations of  $\text{HII/HI}$  as correlated with compression effects in the density wave theory of galactic structure.

Figure 7. A comparison of the longitude distribution of galactic  $\gamma$ -radiation and 150 MHz synchrotron radiation. The central peak in the synchrotron radiation distribution appears to originate in the central region of the galaxy. The remaining radiation has been interpreted in a phenomenological model given by Price (1973) (shown by the dashed line) which also appears to provide a good representation of the  $\gamma$ -ray distribution.

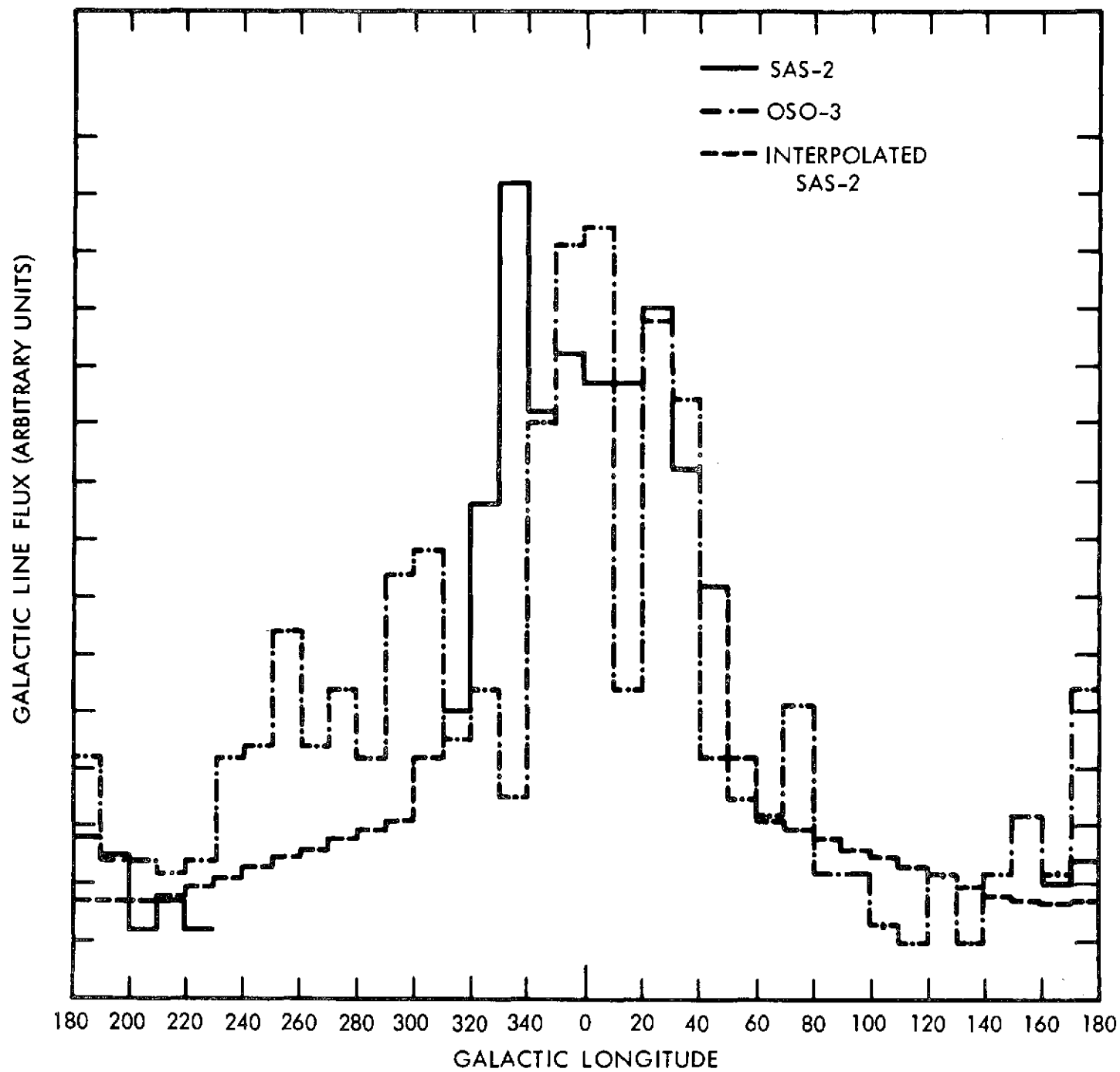
Figure 8. The specific compression rate  $\alpha(\tilde{\omega})$  obtained from the radial velocity data  $v_r(\tilde{\omega})$  based on the obser-



vations of Shane (1972) and Sanders and Wrixon  
(1972, 1973).

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FIG. 1



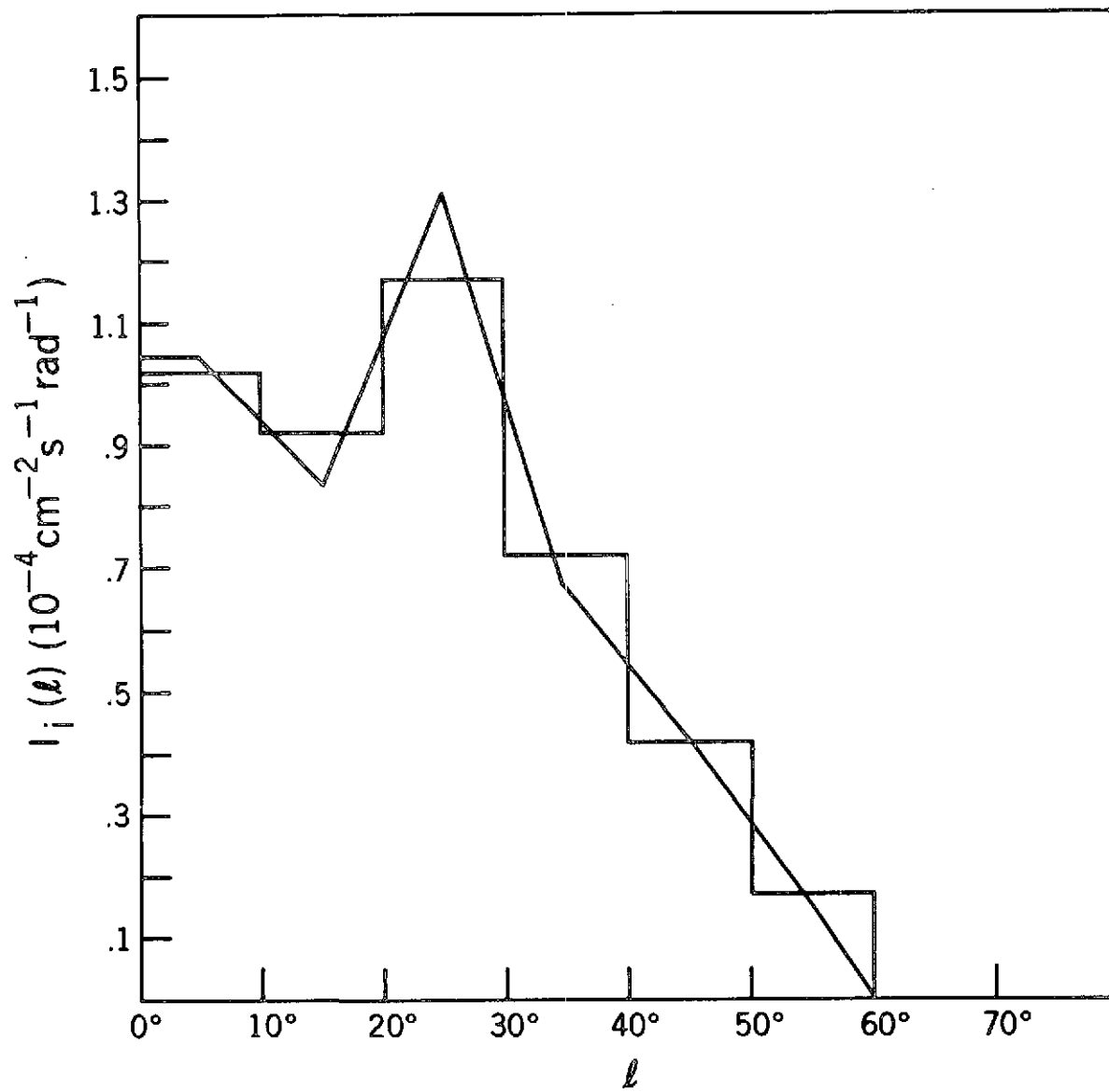


FIG. 2

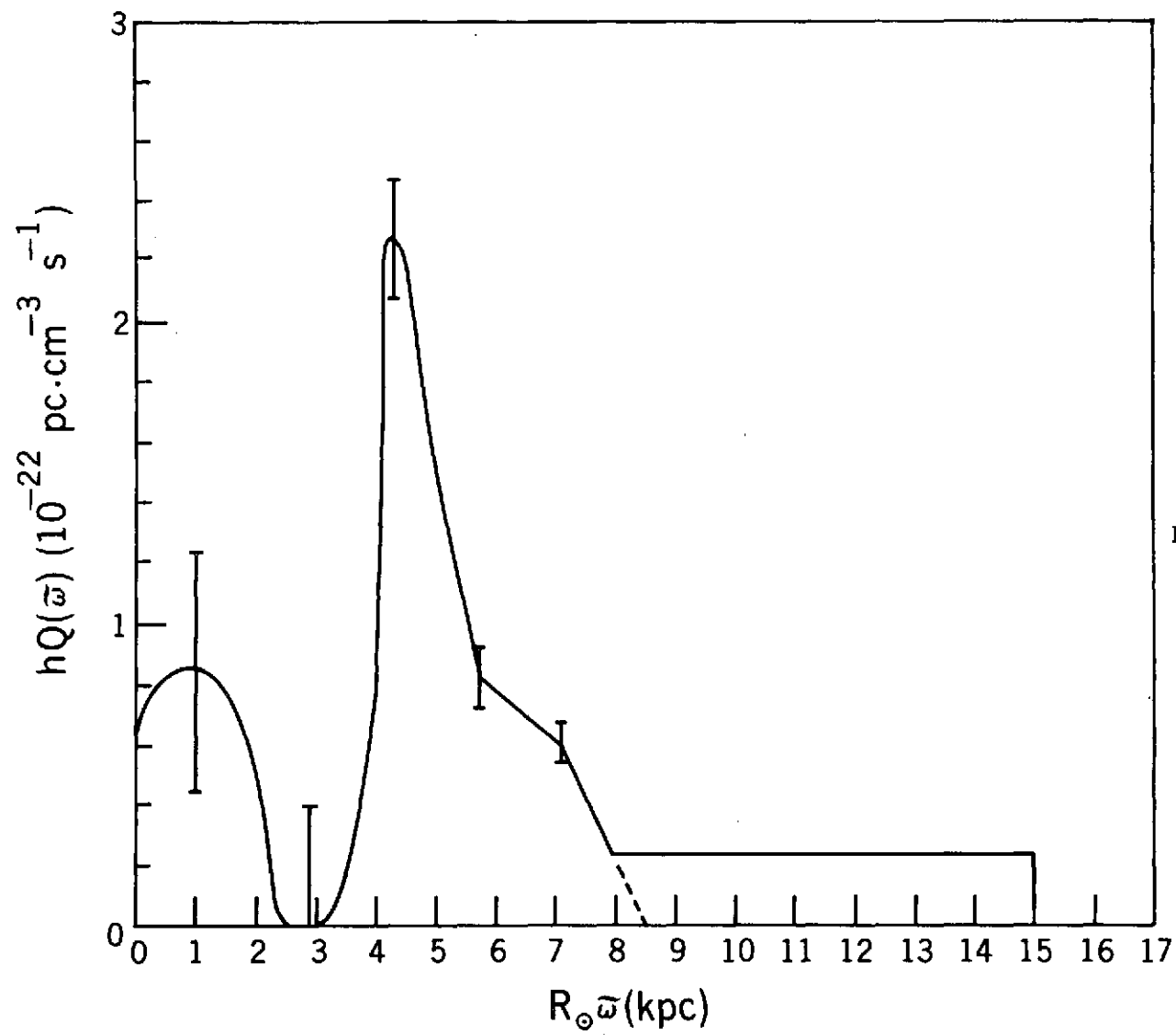
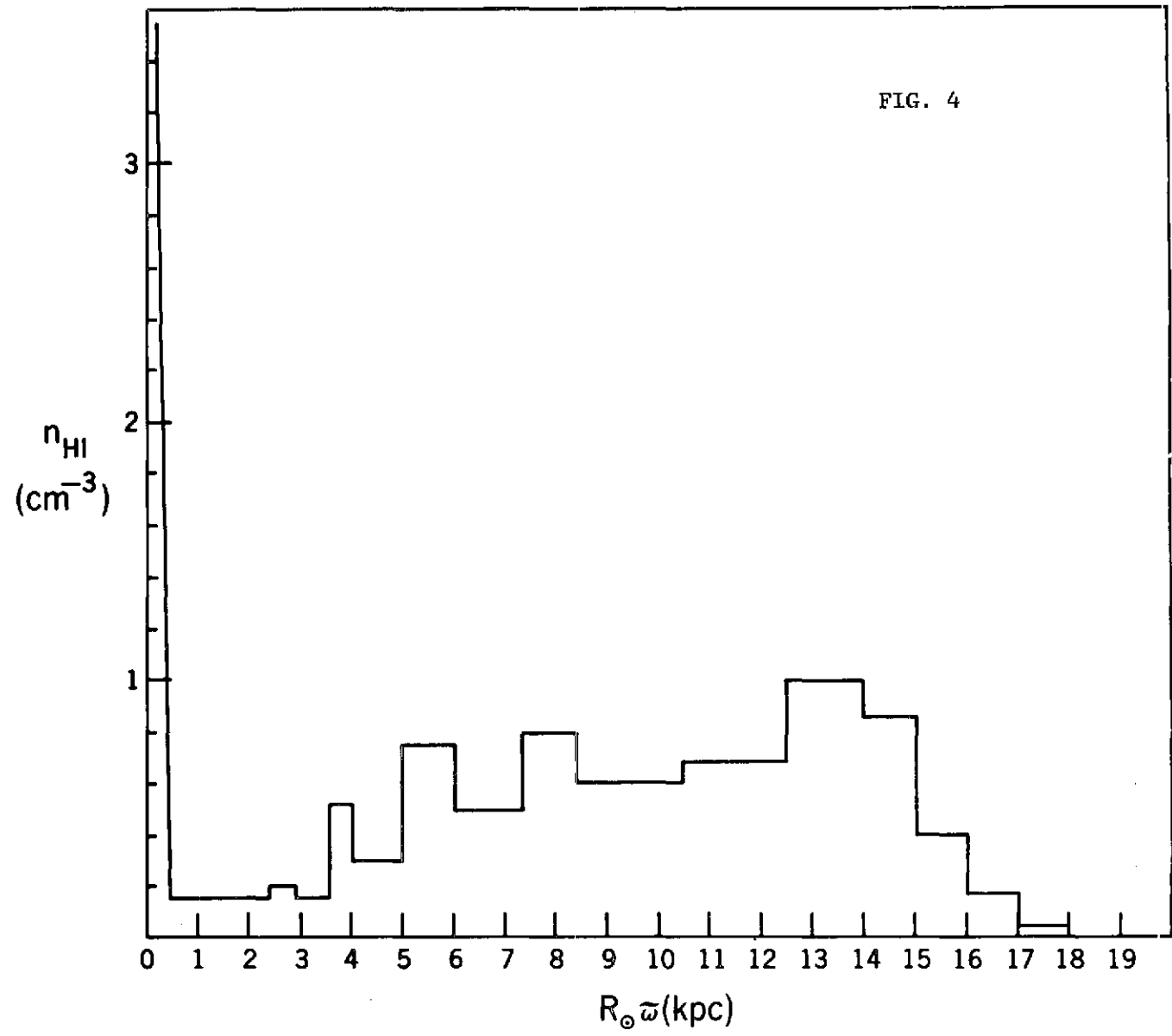
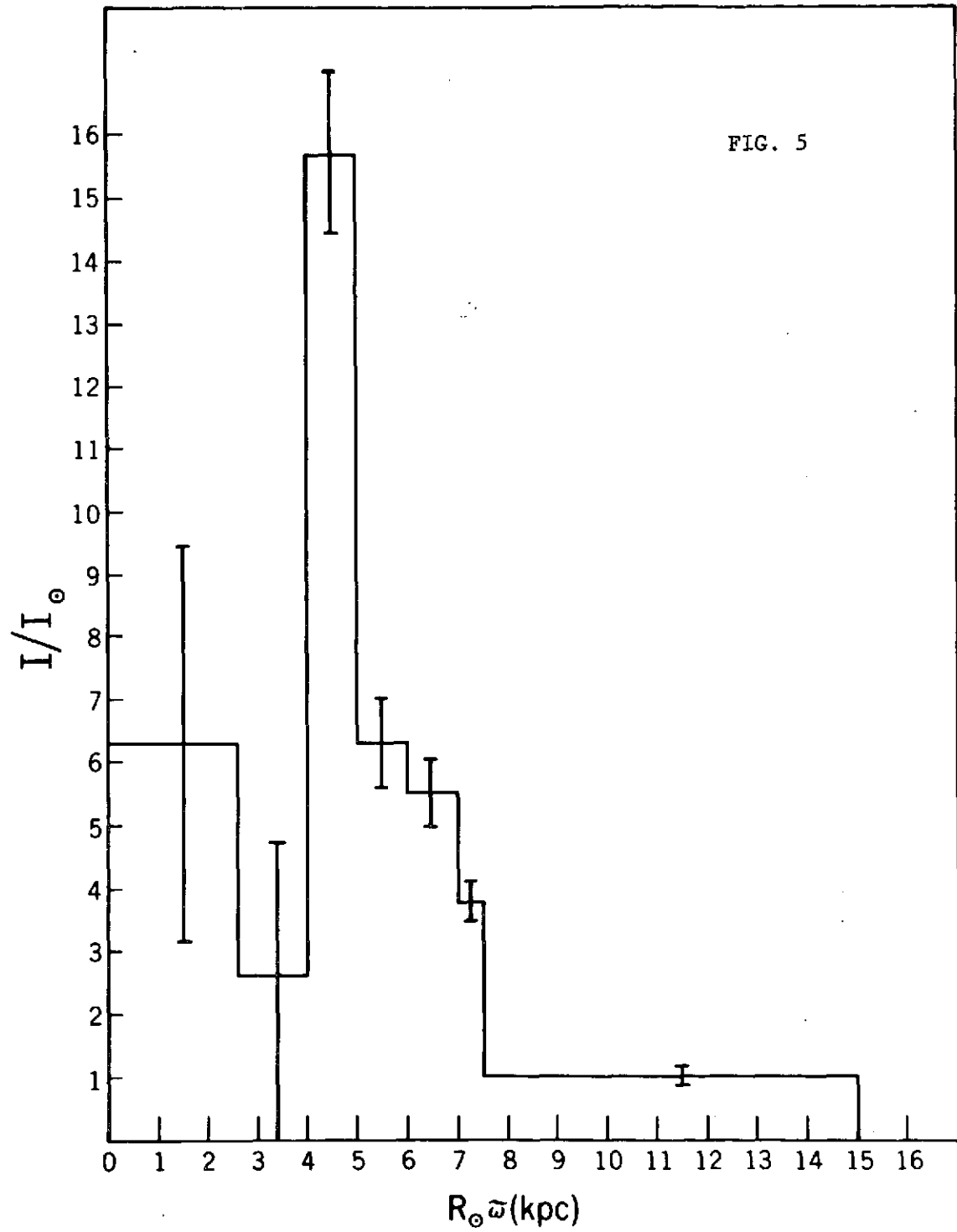


FIG. 3





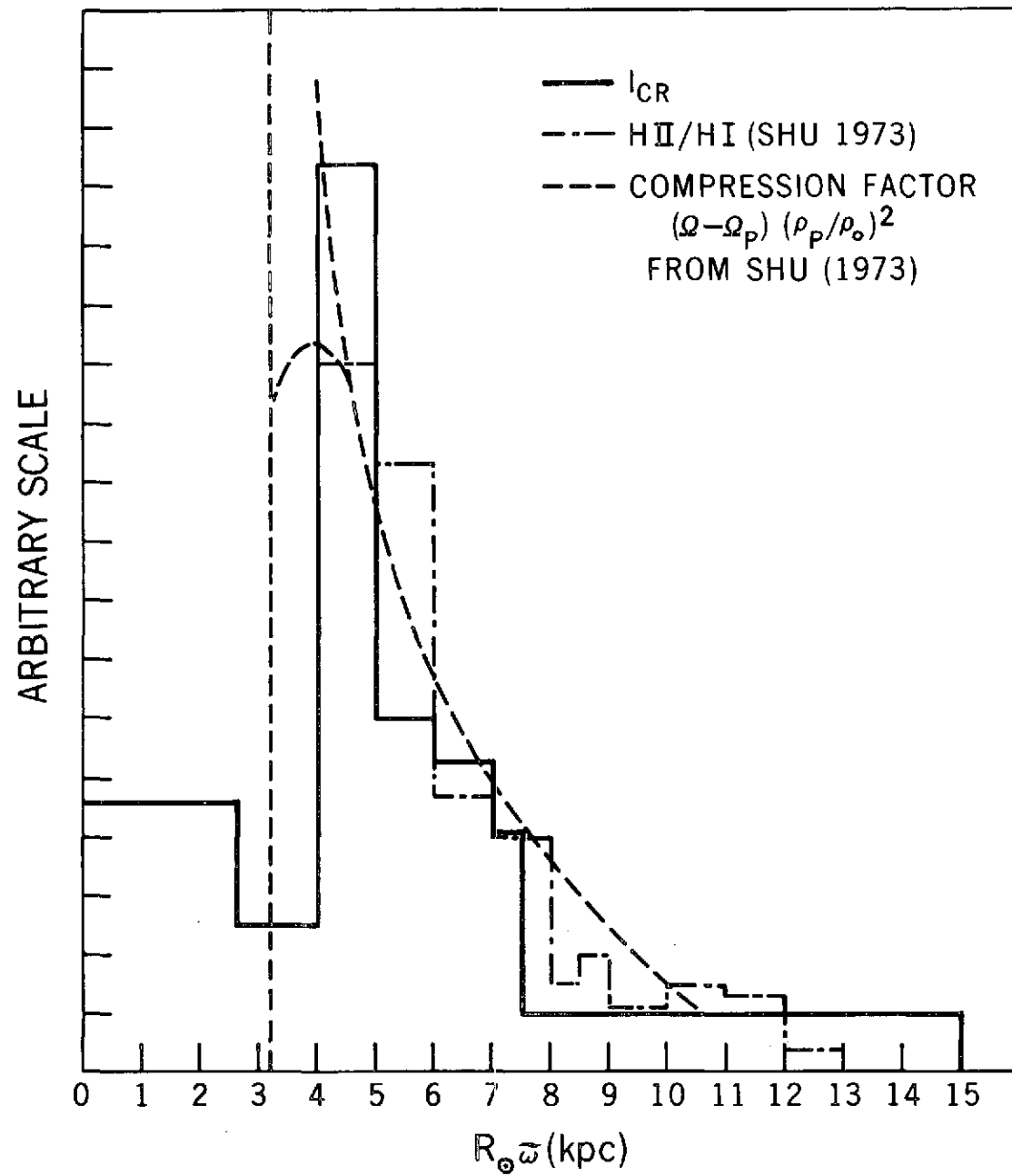


FIG. 6

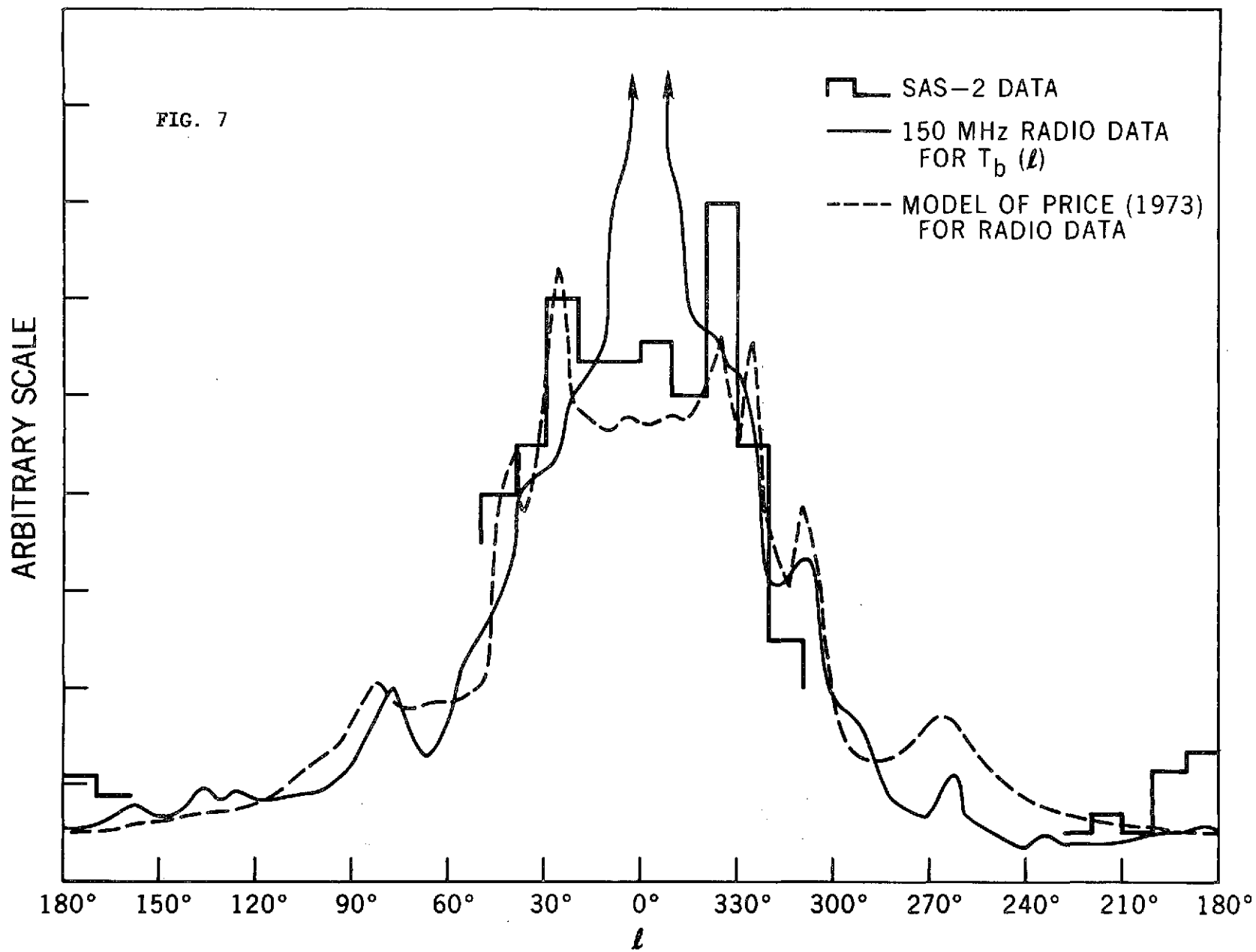




FIG. 8

